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Reduction of Defects in Latex Dipping Production: A Case Study in a Malaysian Company for Process Improvement

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ABSTRACT
Six Sigma is based in large measure on creating a closed-loop business system to reduce company's inconsistency or "variations" of business system and keep it staying on the path to performance and success. Defects, which are the bad variation that have a negative impact on customers and the approaches used to monitor and improve them, can be defined as "process improvement". This paper presents the implementation of process improvement in a latex production company in Malaysia. The Six Sigma Way is proposed and DMAIC (Define-Measure-Analyze-Improve-Control) phases are developed to accomplish the process improvement efforts. These phases had been applied in latex dipping production line that identified as the most critical area of cost compelling to the company.

KEYWORDs **-** *Defects, Dipping process, Latex product, Process improvement, Six Sigma.*

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I. INTRODUCTION

Oxygen mask, stethoscope tubing, adhesive tape, gloves, toys, balloon, swimming cap and rubber band are a few examples of medical and household products made from latex and rubber. These products are essentials for daily life and the demands for it are sky-rocketing day by day [1]. Nowadays, the latex industry has become very competitive and requires high volume production to achieve profitability. Technologies and manufactures also faced with challenging tasks in developing high quality latex product with minimum cost possible. For medical latex products in example surgical gloves, there is also a safety issue concerning how defected products can cause contamination as well as risks in provoking allergic reaction to patients and medical workers [2].

In Malaysia, abundant sources of high quality and natural latex form rubber make it a suitable place for production of latex products. However, the production of these products, results in a lot of waste after manufacturing due to quality problems. Therefore, production capacity usually did not meet order requirements due to high end result of scraps. Late deliveries sometimes occur where in certain cases; company has to bear the costs of compensation. Besides, the other obstacle is high inventory in certain items. Therefore, company needs to adopt suitable process improvement method to solve the problems. Six Sigma is one of the best tools that improve the reliability and quality of products by focusing on the process of reducing defects in manufacturing [3].

A case study in a latex production line in Malaysia was carried out with an objective of finding out a strategy for developing focused solutions to reduce product defects using DMAIC approach from Six Sigma method. Six Sigma is widely implemented in the industry due to its' well structured methodology that enable company to achieve their goal through continuous improvement [4]. DMAIC and Six Sigma are key methods in the process yet as highlighted by [5], lack of implementation model detailing the steps and phases contributes to failure of the program. Six Sigma places a clear center of attention on bottom-line impact in hard dollar savings and company's cash flow [6 & 7]. No Six Sigma project will be approved unless the team determines the investments generated from it. Six Sigma also has been very successful in integrating both human aspects (culture change, training, customer focus, etc.) and process aspects (process stability, variation reduction, capability, etc.). Finally, Six Sigma technique creates a powerful infrastructure for training of champions, master black belts, black belts, green belts and yellow belts [8 & 9].

In this paper, remedial actions are taken to reduce the most serious revealed quality problems produced by one of the common process known as latex-dipping process. This paper is organized as follows: Section 2 provides process improvement concept and the six sigma approach. In Section 3, DMAIC framework is presented and process improvement for a case study towards implementing the DMAIC approach is discussed. Finally, Section 4 concludes the process improvement implementation and possible future work is given.

II. PROCESS IMPROVEMENT CONCEPT AND SIX SIGMA APPROACH

Process improvement is the analysis and redesign of processes to eliminate organizational problems and inefficiencies in small increments, over time, by improving one or two processes at a time. It is done on an operational level (as opposed to radical re-engineering which is done on a strategic level) and is carried out primarily by the people most involved in the process. The incremental process improvement approach builds in small successes that motivate teams to continue. Failure, if it occurs, has less potential to do serious damage because scope is limited to one or two processes at a time. Incremental process improvement can be a good way to realize benefits in quality and organizational performance while bringing people together over a common goal. It can stimulate self-esteem and inspire employees to look for innovative ways to deal with challenges.

There have been many "improvement models" applied to processes over the years since the quality movement began. Most of these are based on the steps introduced by W. Edwards Deming – Plan-Do-Check-Act or P-D-C-A – which describes the basic logic of data-based process improvement. For this paper, the Six Sigma Way, a five-phase improvement cycle is used an approach for problem solving. There are: Define, Measure, Analysis, Improve, and Control – or DMAIC method [10]. It is a closed-loop method that eliminates unproductive steps and also applies technology for continuous improvement approach [11]. Detail study from the perspective of scientific theories on the DMAIC method by [12] shows that it works as problem structuring device by breaking down the problem solving tasks into sequence of generic subtasks. Then, the method will give synergistic benefits and help companies in achieving consistency in operations [13]. Fig. 1 shows the complete cycle of DMAIC in a form of framework for the Six Sigma implementation in the case study company.

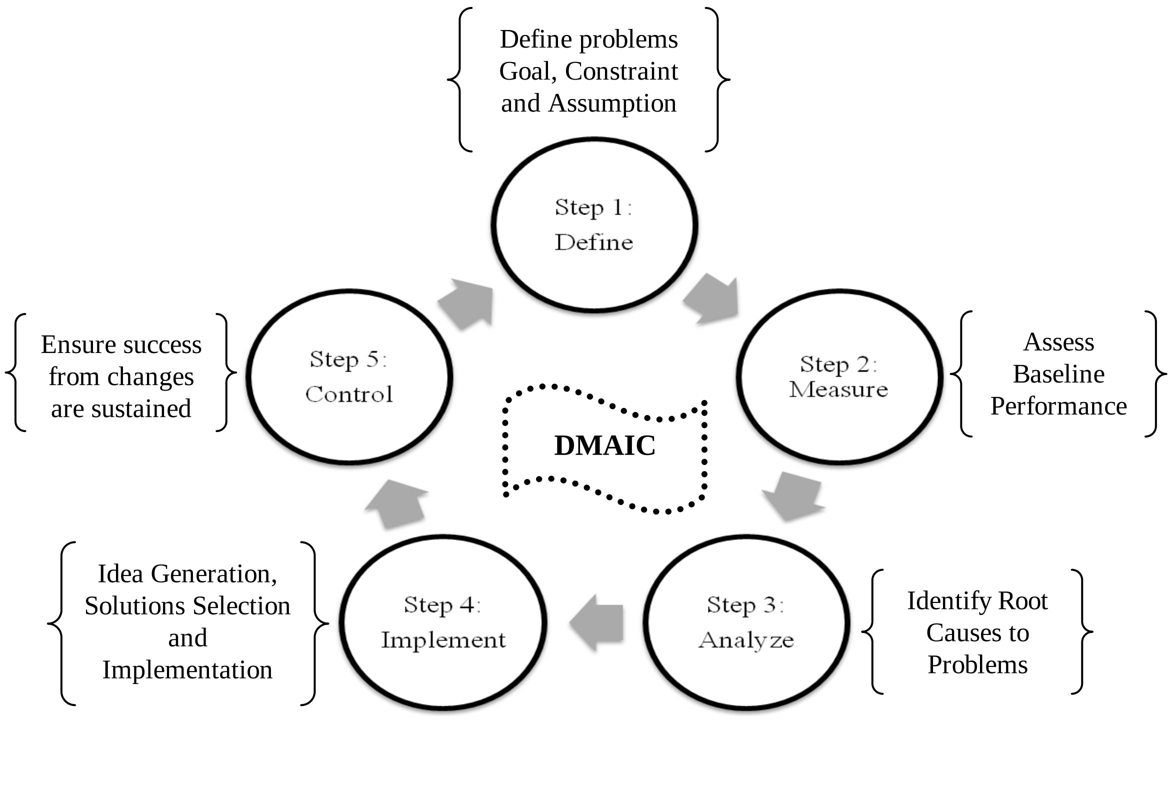

Figure 1: Framework of DMAIC steps conducted in the case study company

III. CASE STUDY

The case study company emphasizes that providing good quality product to its customers by reducing defects is their main goal. This implies a competitive company must have both high quality goods and provide a high quality of service. The company now leads the latex products industry that service local market needs because it goes beyond value-adding activities such as logos printing. It constantly adds and refines its production capacity and improvements are done with an eye of possible dismantling due to offshoring, outsourcing and the increasingly integrated global supply-chain. Capacity adding and improvement must constantly focus on taking advantage of the present void in the market but must be ready for incremental adjustment or major redesign for future.

The proposed Six Sigma approach is applied in the latex dipping production line of the company. Dipping process is the favourite process of latex product like glove, balloon, condom and toys [14]. The dipping process is a process where coagulant-coated formers are dipper into rubber latex at a certain dipping rate and characteristics [15]. Then the rubber films are removed while the formers are cleaned using acidic and some basic solutions so that it can be reused for the new dipping process. The process allows for production of thin latex product with various types and colour that can meet individual customer's need. The finished product from latex dipping also can be decorated in numbers of ways like printing or stamping. In the company, chemicals used in dipping process are found to have great influence in products' quality. The raw material, rubber latex and chemical added such as colour pigment, wetting agent, dispersing agent, powder, coagulant and etc are rigorously controlled in order to attain high quality product. The mechanical action of the process also affects the quality of the final products. The framework introduced in this paper focuses on the process of reducing defects created during the whole dipping process. The five-phase improvement cycle, DMAIC is grounded in the original PDCA cycle and will be used to apply to Process Improvement effort.

3.1. STEP 1: DEFINE PROBLEMS, GOAL, CONSTRAINT AND ASSUMPTION

For the first step of the process improvement effort, problems that occurred in the company are clarified and made clear who is the customer (downstream and end users) served and impacted by this problem. First, the Project Rationale has been clearly understood by the improvement team and ensured that the team began to focus on a problem. Problems are collected from three section which are function and printing department (downstream) as well as complaints from end-users at the case study company. In function department, bad quality of the latex products affects the speed and quality of product decoration and installation. High rate of bursting delays the work of product decorators. This in turn increases the cost of operation of the company in term of labor cost (time) and material cost (rubber latex and helium gas). The quality of latex product in terms of consistency in size, shape and tone affects the aesthetics of the final look of the decoration. The final look of decorations is often perceived as the quality measure of a product decorator.
The similar issues occurred in printing department. The quality of latex products affects the speed and quality of printing process. High bursting rate also delays the printing process. This has increased the time to complete the particular order and meet the deadline, while the quality of latex product in term of consistency in even shape after inflation affects the printing visual. The aesthetic of printing is often professed as the quality measure of a customer.

Another trouble faced by the company is complaints from the customers about the skewed logos printed on the finished latex product. The customers stand for product decorators, event companies, and direct consumer who purchase the product. Due to the quality problems that occur, result in end users to ship back the products. Sometimes, the company has to re-produce the products or offer cheaper price for its customers. This increase the company financial cost and lost in term of profit. Hence, in this stage, the objective is defined as to reduce the percentage of balloons defects. In sigma language, it increases from 2 sigma level to 4 sigma level.

To implement the Six Sigma way in the company, constraints and assumptions are defined in order to narrow down the project scope. In this process improvement effort, the scope is limited to achieving incremental change instead of complete re-engineering or redesign of process. There are other processes that create products defects but this project is only limited to improvement in dipping machine production process and not management process or issues. In other words, defects created by the dipping machine are going to be studied. Furthermore, this study does not involve improvement in material or material engineering. The last element consist in this stage is identify downstream and customer requirements. Thus surveys are done to ensure the problem and goal is defined in term of customer requirements and endows with information on possible defect rate measures for the next step. For downstream department, they require pinhole free product so that this will not affect the speed of printing and installation. The products also need to be in an even shape after inflation so that the logos printed are not skewed. Lastly, products without color patches, without internal and external surface stickiness and good bead rolling are required as to ensure it will not delay the work of decorators. While for end users, they are more concern about the products aesthetic, no breakage, lasted long, easy to use, cheap and chemical friendly.

3.2. Step II: Assess Baseline Measure

In the second stage, baseline measure is targeted to the total reject quantity. To narrow down the scope, the total reject is classified into different type of defects and a list of deficiency was produced. Next, data were gathered from three targeted fields which are printing department, function department and end users. For each type of defect listed above, 10 samples (30 latex products per sample) were collected and the number of that particular type of defect was recorded. From the three departments in the company, it can be found out that the most significant defects to the problem are latex products with uneven wall thickness, uneven shape after inflation and bursting.

3.3. Step 3: Analyze Process and Identify Root Causes to Problems

The third step in the improvement plan conducted in the case study company is to analyze the process and then identify the root causes to each problems or defects that occur. In doing so, latex-dipping process is first studied and analyzed. In dipping process, the mechanical action of making latex products affects the final product quality. In order to make a product, formers or moulds of the latex product are hanging straight down and installed on a chain. Then the formers are dipped into the coagulant and liquid latex as the chain moves. The latex runs on the formers affects the evenness of the wall of the product. The common problem during this stage is that the product's nozzle will be thinner while the end of the product will be thicker and stronger.

Continuing the process, the chain moves horizontally and inclined down when going to dip into the compounded liquid latex. Then it slants at an angle up and moves horizontally again to the next station. When the formers incline up, the latex started to run and at the same time, it started to coagulate as well. This will cause one side wall is a little thicker than the other. The latex product will blow up with a curve and can be seen that the product with uneven shape after inflation. This situation also contributes to high bursting rate of product during usage.Some purchase order from customers required that logos to be printed on the products. For this purpose, the products are sent to printing department. During this process, uneven shape after inflation slows down the logo printing rate. After the product is 90% expanded, the printing process is conducted. The printed logo will be skewed if the products are not expanding evenly. This has a great effect on product aesthetic. Therefore, the analysis of latex-dipping process managed to identify three types of product defect. The defects are:

1. Defect 1 - Uneven shape after inflation
2. Defect 2 - Uneven wall thickness
3. Defect 3 - High bursting rate

Once the defects were identified, the improvement process continued with building a list of possible root causes for defects on latex products. In this framework, the 4M's (Material, Machine, Measure and Method), and 1P (People) in fish bone method is used to find out the root causes. By establishing categories of potential causes, it helps to ensure a team thinks of many possibilities, rather than just focusing on a few typical areas. Through these diagrams, some main suspect causes could be identified. It also provides the focus to assist process and data analysis. The root causes for Defect 1 are shown with Fish-Bone Diagram in Fig 2.

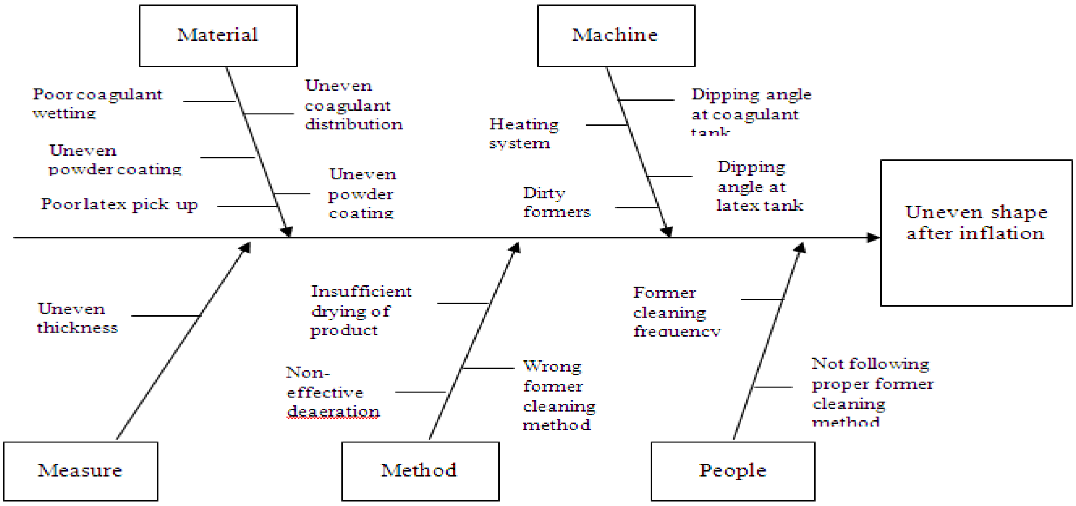

Figure 2: Root Causes of Uneven Shape after Inflation

For Defect 2 which is uneven wall thickness of the latex product, the root causes are as shown in Fig. 3.

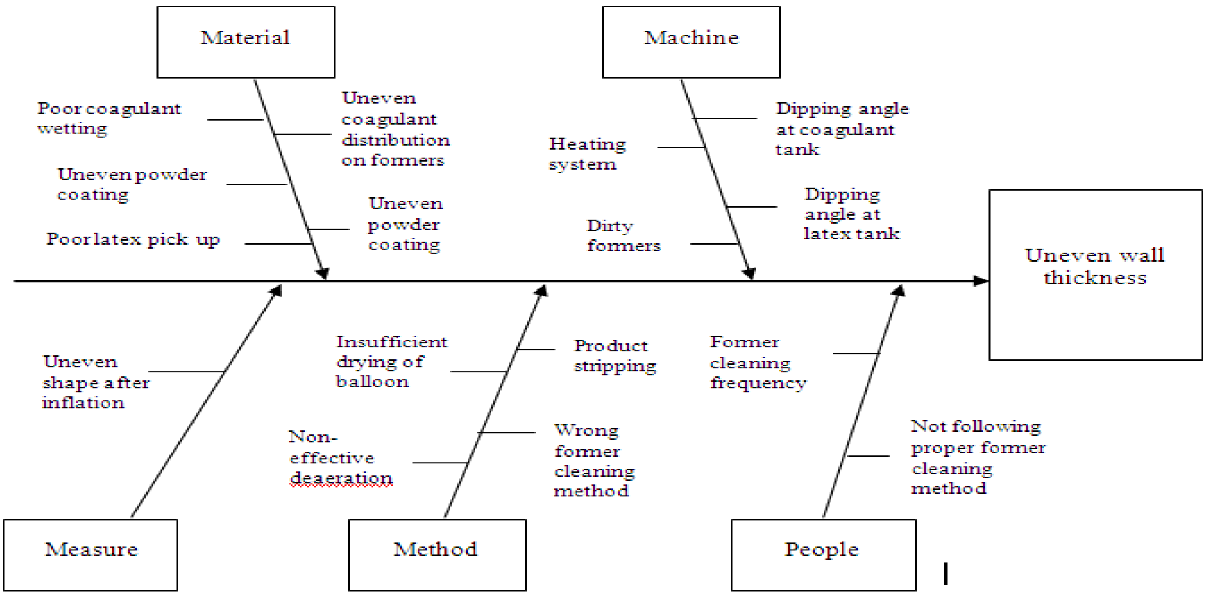

Figure 3: Root Causes of Uneven Wall Thickness

By referring to Fig.2 and Fig.3, discussion conducted shows that Defect 1 and Defect 2 share similar root causes. From the analysis, uneven coagulant and latex distribution cause the uneven product shape after inflation and uneven wall thickness of the end product. Besides uneven liquid latex distribution on the product's formers, there are other factors that affect shape after inflation. In 'Material' factor, poor coagulant wetting on formers causes the jagged coagulant allocation. When dipped into liquid latex, this will cause uneven and poor latex pick up. Therefore, the product will form a curve shape after inflation and during usage. Another root causes identified is that improper former cleaning cause's uneven wall thickness. After the latex products are stripped from their formers, the formers have to go through water cleaning before start another cycle. This process is known as coagulant dipping. If the formers are not properly cleaned, then remaining coagulant is not totally removed and when it later dipped into latex, the situation will cause uneven latex pick up. This is the root cause of uneven wall thickness happened. Furthermore, when the products are pulled out from the formers, the viscous latex is going to run. This slightly affects the wall thickness of the finished products. Once all the root causes of Defect 1 and Defect 2 were identified, fish-bone analysis was conducted for Defect 3. The root causes are shown in Fig. 4.

The other main defect that contributes to the towering reject level is high products bursting rate. The initial measure can be made by pin hole and fish eye occurrence. If the pin hole exists, the product will burst during inflation. Same as fish eye existence as well, the small particular section wall thickness is thinner. While inflating, the product expanded and the section could not stand the strength and burst then. Analysis of the dipping process shows that the presence of pin hole always closely related with the former cleanliness. Impurity exists to formers result in blockage to latex distribution. Hereby the product formed will have pin hole types of defect. Impurity presence at former caused improper cleaning way and cleaning frequency. Ineffective deaeration also causes scattered impurity in former. On the other hand, no filtration system to trap lumps in coagulant and liquid latex is another cause to impurity presence.

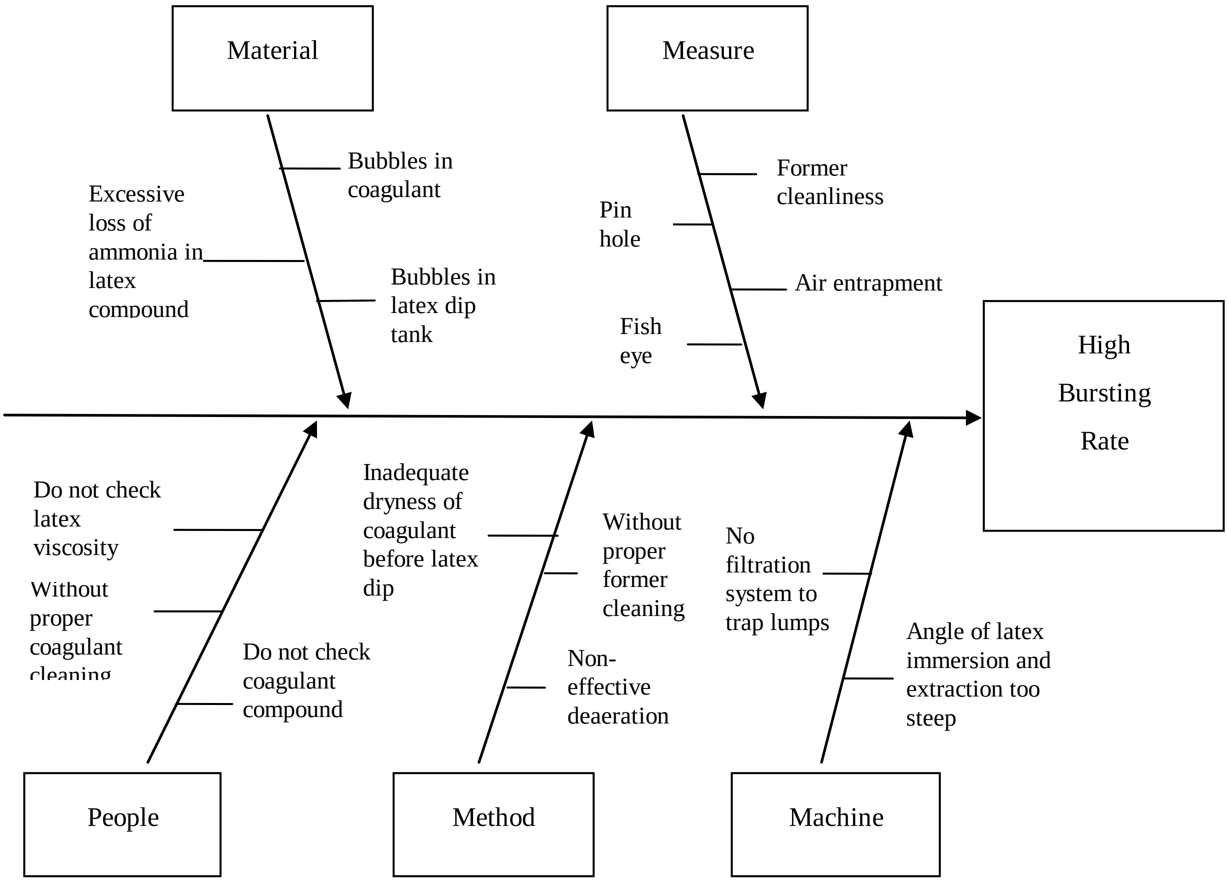

Figure 4: Root Causes of High Bursting Rate

Another observation shows that the presence of fish eye directly interrelated with the air entrapment in the coagulant or liquid latex. This factor is also the reason to the uneven both coagulant and latex distribution on formers. The other possibilities to high bursting rate are inadequate dryness of coagulant before latex dip and insufficient curing time after stripping. This means after heating process and product take-off from the formers, the products need some time to cure and could not continuing with the logo printing process at the very instance.

From the fishbone diagrams in Fig.2, 3 and 4, it could be understand that different defects also share same root causes. Then the most common root causes were extracted from the fishbone diagrams and Pareto chart is used to identify the most common occurrences or causes of the highest defect rates. Although there is no absolute certainty of root causes, data about the process and its performance are analyzed to help stratify the problem and potential root causes were recognized. The main cause had been verified through logical analysis and based on expert-judgement of the workers. The process and the place where the cause was suspected to be happening were checked through observation.

3.4. Step 4: Idea Generation, Solutions Selection and Implementation

It's important during Improve to look for ways to maximize the benefits of efforts. Once all the defects and its root causes are identified, the best way to start the Improve phase is to find out the possible actions or ideas that will help to address the root causes of the problem and achieve the goal. After that, which of these ideas could form workable potential solutions are identified. Based on the case study, several ideas of how to solve the problems are collected for workers involved in the process. Then, the redundant ideas were eliminated. Then the remaining ones are organized and the list was narrowed to five ideas. After that, some selection criteria (as shown in Table 1) to assist in making the most appropriate solution decision are identified.

Table 1: Selection Criteria

No.	Selection Criteria
1.	Ease of handling
2.	Ease of implementation
3.	Cost to operate
4.	Durability
5.	Portability
6.	Require less/little maintenance
7.	Convenience
8.	Ergonomics

Ideas generated in the Improve phase are like raw material to be refined to have real value to the organization. Usually, Six Sigma solutions will be combinations of ideas that together make up a plan. It's important to recognize that solution selection may not be an either/or choice. Combination several actions into one plan are okay. On the other hand, a "shotgun" solution that sprays many different mini-fixes at the problem can be a big waste of resources. Here, Matrix tool is used to select the best applicable solution. The proposed ideas go through concept screening and concept scoring then the final decision is made.Based on the case study, solutions for major defect rate are investigated. From the defect analysis in the previous step, it could be found out that products do not expand evenly and uneven wall thickness shared the common root causes. Hence, means of settlement for these two defects are almost similar. Hereby, both defects were under the same category and solution statements could be created together. In, addition, the improvement methods for high bursting rate was also investigated.

i) Referring to Defect 1: uneven shape after inflation and uneven wall thickness, some improvement methods are proposed.

a. Better coagulant wetting
b. Modify chain track and angle
c. Modify dip tank
d. Frequent formers cleaning
e. Sufficient formers drying using fan
f. Reference (current machine design)

Next, two Criteria Matrix were set up so might conduct comparison among improvement methods based on the selection criteria. Firstly concept screening matrix was constructed (refer to Table 2). Rough initial improvement methods were evaluated and coarse comparative rating system was used.

Table 2: Concept Screening for Uneven shape after Inflation Improvement Methods

Selection Criteria	Improvement Methods					
	A	B	C	D	E	F
Ease of handling	-	0	+	0	0	0
Ease of implementation	+	0	+	-	+	0
Cost to operate	0	-	-	+	+	0
Durability	0	+	0	-	0	0
Portability	0	0	+	+	+	0
Require little maintenance	-	0	0	+	+	0

Convenience Ergonomics	- 0	+ 0	+ 0	- -	- -	0 0
Sum +'s Sum 0's Sum –'s	1 4 3	2 5 1	4 3 1	3 1 4	4 2 2	0 8 0
Net Score Rank Continue?	-2 6 No	1 3 Combine	3 1 Yes	-1 5 No	2 2 Yes	0 4 Combine

Additional resolution is needed to distinguish among opposing improvement methods, a finer scale is used as listed in Table 3.

Table 3: Selection Scale

Relative Performance	**Rating**
Much worse than reference	1
Worse than reference	2
Same as reference	3
Better than reference	4
Much better than reference	5

After some alternatives were eliminated, the team moved on to concept scoring (refer to Table 4). More detailed analyses were conducted and quantitative evaluations of the remaining concepts were accomplished.

Table 4: Concept Scoring for Uneven shape after Inflation Improvement Methods

		Improvement Methods					
		B&F		C		E	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Ease of handling	25%	3	0.75	4	1.0	3	0.75
Ease of implementation	20%	3	0.6	3	0.6	3	0.6
Cost to operate	10%	2	0.2	2	0.2	4	0.4
Durability	10%	4	0.4	4	0.4	3	0.3
Portability	5%	2	0.1	5	0.25	4	0.2
Require little maintenance	15%	3	0.45	3	0.45	4	0.6
Convenience	10%	4	0.4	4	0.4	2	0.2
Ergonomics	5%	3	0.15	3	0.15	2	0.1
	Total score	3.05		3.45		3.15	
	Rank	3		1		2	
	Continue?	No		Develop		No	

Lastly, with the guide gained from these selection matrixes, final decision could be made and then could go for further step, which is implementing process improvement.

ii) Referring to Defect 3, high bursting rate; the similar method was used to choose the workable improvement ideas. Some proposed improvement methods are:

a) Proper former cleaning
b) Sufficient drying using fan
c) Adequate dryness using oven
d) Low foaming wetting agent for coagulant
e) Longer curing time
f) Reference (current machine design)

For Defect 3, concept screening is as shown in Table 5 while scoring shown in Table 6.

Table 5: Concept Screening for High Bursting Rate Improvement Methods

	Improvement Methods					
Selection Criteria	A	B	C	D	E	F
Ease of handling	0	0	-	-	-	0
Ease of implementation	-	+	+	+	0	0
Cost to operate	+	+	+	0	-	0
Durability	0	0	0	0	+	0
Portability	+	+	-	0	-	0
Require little maintenance	+	+	-	-	0	0
Convenience	0	-	0	-	-	0
Ergonomics	-	-	0	0	0	0
Sum +'s	3	4	2	1	1	0
Sum 0's	3	2	3	4	0	8
Sum –'s	2	2	3	3	4	0
Net Score	1	2	-1	-2	-3	0
Rank	2	1	4	5	6	3
Continue?	Yes	Yes	No	No	Combine	Combine

Table 6: Concept Screening for High Bursting Rate Improvement Methods

		Improvement Methods					
		A		B		E&F	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Ease of handling	25%	4	1.0	4	1.0	3	0.75
Ease of implementation	20%	4	0.8	5	1.0	3	0.6
Cost to operate	10%	3	0.3	2	0.2	3	0.3
Durability	10%	3	0.3	3	0.3	3	0.3
Portability	5%	3	0.15	2	0.1	3	0.15
Require little maintenance	15%	4	0.6	4	0.6	3	0.45
Convenience	10%	3	0.3	3	0.3	3	0.3
Ergonomics	5%	3	0.15	3	0.15	3	0.15
	Total score	3.6		3.65		3.0	
	Rank	2		1		3	
	Continue?	Develop		Develop		No	

For both defects stated earlier, the improvement methods that score the highest rank are going to be implemented. To make balloons with good quality, the improvement team got full support from the Managing Director and approval to start the implementation. And, the company is will to scatter large sum of money to invest for new equipment. The team starts planning for the implementation by making new ordering and delivery procedure of the hydraulic system. Within couple of weeks, the hydraulic system was installed at the machine, at the bottom of the latex dip tank. Based on the initial machine design, the formers are dipped into the compounded liquid latex with eight colours per cycle. Usually one or two colours of products are needed per order made by customers. The remaining balloons are kept as inventory. Besides, it is time consuming to clean the tank in order to change other coloured liquid latex. With the new design, the dip tank can be taken out if not used. This means, the different coloured liquid latex tank can be installed or remove in accordance with the demand. Besides, the cleaning process and production can be run simultaneously. Production lead time as well as quality problem can be reduced. The inventory can be reduced too at the same time can meet customer requirement and diminish late delivery. To make products with even wall thickness from top to bottom, the company has to invest in expensive equipment to spin the formers as they turned over. The task is tuff as new design for the chain and requires chain speed adjustment. Niggling maintenance chore is needed too. The company decided to use the idea proposed above which up-down hydraulic dip tank is. The chain moves horizontally without changing the steep angle at the dip tank. Good quality products can be produced and it is ease of handling in term of maintenance. Compliant with another defect which is high bursting rate, the company employed other improvement methods to solve this problem. The method used is utilizing fans to provide sufficient formers and coagulant drying as well as better deaeration. On the other hand, the method of cleaning process is probed and additional former cleaning frequency is needed to make sure no impurity particles are stickled on the formers. This method is desirable as it involves less cost to operate and requires little maintenance. The company has a backup production method that is hand dipping so the new system would not cause even more late delivery or greater defect rate if it did not work. After the improvement process is done, the improvement team took measure on the rate of products defect. From the results obtained, the defect rates have been reduced. In sigma language, the average defect rates develop from 2 sigma level to 4 sigma level.

3.5. STEP 5: ENSURE SUCCESS FROM CHANGES ARE SUSTAINED

Control is the last stage of DMAIC and it also is the beginning of the sustained improvement and integration of the Six Sigma effort as DMAIC is a closed-loop cycle. Both short- and long-term challenges of sustaining Six Sigma improvement and building all the concepts and methods are explored into an ongoing, cross-functional management approach. It is considered as additional effort that will be continued by the case study company.

IV. CONCLUSION

In this Six Sigma implementation in a case study company, the total rejects due to high defect rate have been reduced after remedial actions are taken. The company invested in hydraulic system along with 'up-down' latex dip tank and this purchasing and installation of equipment was completed within one month. In accordance with the declined defect rate, the capacity could also meet customer requirements well. As a result of this, delivery on time as well as good quality products can be achieved. By using the new hydraulic system on latex dip tank, high inventory in certain items can be reduced to minimal. This is because the manufacturer only runs the production according to the purchase order. It brings success in applying it to the company production line. This project brings challenges of launching, leading and preparing people for the Six Sigma effort. Since the defect rates have been reduced after adopting the continuous process improvement method, the company could look into investigation on other improvement efforts to increase its marginal profit.

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BIOGRAPHIES

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